

Time & Frequency Bulletin

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NIST TIME & FREQUENCY BULLETIN
(Supersedes No. 389 April 1990)

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1. GENERAL BACKGROUND INFORMATION

ABBREVIATIONS AND ACRONYMS USED IN THIS BULLETIN

APL	-	John Hopkins University Applied Physics Laboratory	
BIH	-	International Time Bureau, France	
CCIR	-	International Radio Consultative Committee	
CRL	-	Communications Research Laboratories, Japan	
Cs	-	Cesium standard	
CSIRO	-	Commonwealth Scientific and Industrial Research Organization, Australia	
GOES	-	Geostationary Operational Environmental Satellite	
GPS	-	Global Positioning System	
IEN	-	National Institute of Electronics, Italy	
INPL	-	National Physical Laboratory, Israel	
LORAN	-	Long Range Navigation	
MC	-	Master Clock	
MJD	-	Modified Julian Date	
NIST	-	National Institute of Standards & Technology	
NPL	-	National Physical Laboratory, England	
NRC	-	National Research Council, Canada	
NOAA	-	National Oceanic and Atmospheric Administration	
OP	-	Paris Observatory, France	
PTB	-	Physical Technical Federal Laboratory, Germany	
SI	-	International System of Units	ns - nanosecond
SV	-	Space vehicle	μs - microsecond
TA	-	Atomic Time	ms - millisecond
TAI	-	International Atomic Time	s - second
TAO	-	Tokyo Astronomical Observatory, Japan	min - minute
TUG	-	Technical University of Graz, Austria	h - hour
USNO	-	United States Naval Observatory	d - day
UTC	-	Coordinated Universal Time	
VLF	-	very low frequency	
VSL	-	Van Swinden Laboratory, Netherlands	

2. TIME SCALE INFORMATION

The values listed below are based on data from the BIH, the USNO, and the NIST. The UTC - UTC(NIST) values are extrapolations since UTC is computed more than two months after the fact. The UTC(USNO,MC) - UTC(NIST) values are averaged measurements from NAVSTAR satellites 3,4,6, and 8 (see references on page 6).

0000 HOURS COORDINATED UNIVERSAL TIME

APRIL		UT1 - UTC(NIST)	UTC - UTC(NIST)	UTC(USNO,MC) - UTC(NIST)
1990	MJD	(± 5 ms)	(± 0.2 μs)	(± 0.04 μs)
5	47986	+128 ms	0.4 μs	1.62 μs
12	47993	+111 ms	0.4 μs	1.59 μs
19	48000	+97 ms	0.4 μs	1.54 μs
26	48007	+79 ms	0.4 μs	1.51 μs

INTERNATIONAL TIMING CENTER COMPARISONS VIA GPS COMMON-VIEW

The table below is a weighted average of the indicated GPS satellites used as transfer standards to measure the time difference of Timing Center (i) - UTC(NIST) by the simultaneous common-view approach (see references, page 6). The day-to-day variations of this technique are a few nanoseconds and the accuracy is about 10 ns. The time of the measurement is interpolated to 0000 UTC for the particular MJD ending in 9. These data are prepared for the BIPM for the computation on TAI and of UTC. All differential delays are 0 unless otherwise noted.

UTC(i) - UTC(NIST) (ns)		MJD			
UTC(i)	SV NUMBERS	47979	47989	47999	48009
UTC(APL) - UTC(NIST)	3,6,9,11,12,13,14	-515	-648@	-888	-798
UTC(CRL) - UTC(NIST)	3,6,9 12	833+	823	758	754
UTC(CSIRO) - UTC(NIST)	++	24876+	24970	24967	25158
UTC(IEN) - UTC(NIST)	11,12,13,14	1371+	1385	1411	1427
UTC(INPL) - UTC(NIST)	VIA OP	-162636+	-164729	-166875	-169067#
UTC(NPL) - UTC(NIST)	3, 11,12,13,14	2728	2791	2813	2833
UTC(NRC) - UTC(NIST)+++	3,6,9,11,12,13,14	798+	693	543	362
UTC(OP) - UTC(NIST)!	3, 11,12,13,14	1104+	1150	1153	1152
UTC(PTB) - UTC(NIST)	11	-3280	-3248	-3234	-3212
UTC(TAO) - UTC(NIST)	3,6,9, 12,	5006	4835	4668	4522
UTC(TUG) - UTC(NIST)	3, 11,12,13,14	2839+	2592	2346	2103
UTC(USNO,MC) - UTC(NIST)	3,6,9,11,12,13,14	1662	1618	1550	1503
UTC(VSL) - UTC(NIST)	3, 11,12,13,14	-2214+	-2220	-2234	-2222

+ These values have been updated from those printed in last month's Bulletin.

++ UTC(CSIRO) - UTC(NIST) is computed from the average of CRL, TAO, & WWVH.

+++ UTC(NRC) - UTC(NIST) has a differential delay of 41.2 ns; all other comparisons are computed using zero (0).

@ APL experienced a frequency shift of approximately 30.0 E-14 (NET) between MJD's 47988 - 47998. Therefore, the value for MJD 47989 was computed from the raw, unfiltered data.

! OP experienced a frequency shift of approximately -10.0 E-14 on MJD 47983.

The value for this station for MJD 48009 was extrapolated forward from MJD 48007.

3. UT1 CORRECTIONS AND LEAP SECOND ADJUSTMENTS

The master clock pulses used by the WWV, WWVH, WWVB, and GOES time code transmissions are referenced to the UTC(NIST) time scale. Occasionally, 1 second is added to the UTC time scale. This second is called a leap second. Its purpose is to keep the UTC time scale within ± 0.9 s of the UT1 astronomical time scale, which changes slightly due to variations in the rotation of the earth.

Positive leap seconds, beginning at 23 h 59 min 60 s UTC and ending at 0 h 0 min 0 s UTC, were inserted in the UTC timescale on 30 June 1972, 31 December 1972-1979, 30 June 1981-1983, 30 June 1985, 31 December 1987 and 1989. When future leap seconds are scheduled, advance notice will be provided in this bulletin.

The use of leap seconds ensures that UT1 - UTC will always be held within ± 0.9 s. The current value of UT1 - UTC is called the DUT1 correction. DUT1 corrections are broadcast by WWV, WWVH, WWVB, and GOES and are printed below. These corrections may be added to received UTC time signals in order to obtain UT1.

DUT1 = UT1 - UTC	= +0.2 s beginning 0000 UTC on 1 March 1990
	= +0.1 s beginning 0000 UTC on 12 April 1990
	= 0.0 s beginning 0000 UTC on 10 May 1990

4. PHASE DEVIATIONS FOR WWVB AND LORAN-C

WWVB - The values shown for WWVB are the time difference between the time markers of the UTC(NIST) time scale and the first positive-going zero voltage crossover measured at the transmitting antenna. The uncertainty of the individual measurements is ± 0.5 μ s. The values listed are for 1300 UTC.

LORAN-C - The values shown for Loran-C represent the daily accumulated phase shift (in microseconds). The phase shift is measured by comparing the output of a Loran receiver to the UTC(NIST) time scale for a period of 24 hours. If data were not recorded on a particular day, the symbol (-) is printed.

The stations monitored are Dana, Indiana (8970 M) and Fallon, Nevada (9940 M). The monitoring is done from the NIST laboratories in Boulder, Colorado.

DATE	MJD	UTC(NIST) - WWVB(60 kHz) ANTENNA PHASE (μ s)	UTC(NIST) - LORAN PHASE (in μ s)	
			LORAN-C (DANA) (8970 M)	LORAN-C (FALLON) (9940 M)
04/01/90	47982	5.67	+0.32	+0.31
04/02/90	47983	5.66	-0.03	+0.03
04/03/90	47984	5.63	+0.09	-0.02
04/04/90	47985	5.75	+0.01	-0.08
04/05/90	47986	5.69	-0.01	(-)
04/06/90	47987	5.67	-0.23	-0.44
04/07/90	47988	5.65	+0.13	-0.46
04/08/90	47989	5.64	+0.09	+0.15
04/09/90	47990	5.63	-0.01	+0.00
04/10/90	47991	5.74	-0.10	-0.04
04/11/90	47992	5.73	-0.13	+0.03
04/12/90	47993	5.70	+0.05	-0.00
04/13/90	47994	5.69	(-)	(-)
04/14/90	47995	5.68	(-)	(-)
04/15/90	47996	5.66	(-)	(-)
04/16/90	47997	5.65	-0.07	+0.05
04/17/90	47998	5.64	+0.03	-0.28
04/18/90	47999	5.61	+0.16	+0.24
04/19/90	48000	5.68	+0.07	-0.07
04/20/90	48001	5.68	-0.36	-0.34
04/21/90	48002	5.66	+0.09	+0.05
04/22/90	48003	5.64	+0.26	+0.25
04/23/90	48004	5.62	-0.15	-0.08
04/24/90	48005	5.73	-0.08	+0.10
04/25/90	48006	5.75	-0.10	+0.06
04/26/90	48007	5.73	+0.03	+0.05
04/27/90	48008	5.68	-0.21	-0.08
04/28/90	48009	5.68	+0.13	-0.08
04/29/90	48010	5.67	+0.24	+0.26
04/30/90	48011	5.67	+0.24	+0.13

5. GOES TIME CODE INFORMATION

A. TIME CODE PERFORMANCE (1 - 30 April 1990)

GOES/East: Performance within normal limits during this period. An erroneous code synchronization word was transmitted briefly from about 2100-2145 UTC on 23 April, which may have affected receivers' ability to lock to the signal. The GOES-5 satellite is still drifting westward and was at about 74 degrees west longitude on 30 April.

GOES/West: Performance within normal limits during this period, except for the period from about 1700-1800 UTC on 27 April when erroneous position data were transmitted. Also, see note about erroneous synchronization word under GOES/East above.

B. SPECIAL REMINDER: Current satellite locations are 74° West longitude for GOES/East and 135° West longitude for GOES/West.

C. ----- SPECIAL NOTE -----
 In response to concerns from time code users about GOES/East coverage in Europe and Africa if GOES/East operations are shifted to GOES-7, NOAA has reconsidered its previous decision. Currently, the plan is to transfer GOES/East operations from GOES-5 to GOES-2 (an older standby satellite) when GOES-2 drifts into its new location at about 60° West longitude. This transfer of operations is expected to occur about May-July time period and will remain in effect indefinitely. Exact dates will be announced in the GOES status file (NBSGO) maintained in the U.S. Naval Observatory's Automated Data Service (see below for access information) as soon as it is known.

D. FUTURE SATELLITE LAUNCHES: NOAA's present launch schedule for replacement of the current East and West satellites is July 1991 and February 1992, respectively.

E. GOES STATUS REPORTS

A brief message from the NIST giving current GOES time code status information is available from the U.S. Naval Observatory's Automated Data Service computer system in Washington, DC. The message may be accessed 24 hours per day without charge by using a variety of terminals operating at 300, 1200, or 2400 Baud and even parity. Two different sets of telephone access numbers are available: (1) for 300 or 1200 Baud and the Bell 103 standard use (202) 653-1079 (commercial), 653-1079 (FTS), or 294-1079 (Autovon); (2) for 1200 or 2400 Baud with either the CCITT V.22 standard or the Bell standard use (202) 653-1783 (commercial), 653-1783 (FTS), or 294-1783 (Autovon). To receive the GOES status message, use the following procedure:

1. Access the USNO computer database by dialing one of the appropriate telephone numbers above;
2. In response to the prompt for identification, type your name and the name of your organization, followed by a carriage return;
3. Type "@NBSGO" followed by a carriage return to receive the status message at your terminal;
4. Disconnect by typing Control-D.

6. BROADCAST OUTAGES OVER 5 MINUTES AND WWVB PHASE PERTURBATIONS

OUTAGES						PHASE PERTURBATIONS WWVB 60 kHz			
STATION	APRIL 1990	MJD	BEGAN (UTC)	ENDED (UTC)	FREQUENCY	APRIL 1990	MJD	BEGAN (UTC)	ENDED (UTC)
WWVB	NONE					NONE			
WWV	23-24	48004	2355:00	0205:00	2.5 MHz	NONE			
	23-24	48004	2355:00	0145:00	20.0 MHz				
WWVH	NONE					NONE			

7. NOTES ON NIST TIME SCALES AND PRIMARY STANDARDS

The frequencies of the time scales, TA(NIST) and UTC(NIST), are calibrated with the NIST primary frequency standards. The UTC(NIST) scale is coordinated within a microsecond of the internationally coordinated time scale, UTC, generated at the BIH. It is used to control all of the NIST time and frequency services. The last calibration of the relative frequency offset, y , of UTC(NIST) as generated in Boulder, Colorado, gave:

$$1) \quad y_{UTC(NIST)}(\text{July 1987}) - y_{NBS-6}(\text{July 1987}) = (-0.6 \pm 2 (1 \text{ sigma})) \times 10^{-13}$$

for the date shown. This calibration includes a correction for the systematic offset due to room temperature blackbody radiation, which is approximately $(\Delta y_{BB}) = -1.7 \times 10^{-14}$. Using GPS¹, the frequency of TAI for the dates shown were measured to be:

$$2) \quad y_{TAI}(\text{July 1987}) - y_{NBS-6}(\text{July 1987 on geoid}) = (+1.7 \pm 2 (1 \text{ sigma})) \times 10^{-13}$$

where account has been taken of the gravitational "red shift."

Starting 1 January 1975, an accuracy algorithm was implemented to bring the second used in the generation of TA(NIST) closer to the NIST "best estimate" of the SI second (see references, p.6). The relative frequency associated with this "best estimate" is denoted $y_{Cs}(NIST)$. The last calibration (July 1987) covered the period from October 1986 through July 1987.

$$3) \quad y_{Cs}(NIST) - y_{NBS-6} = (+1.4 \pm 2) \times 10^{-13} \text{ (July 1987)}$$

and

$$4) \quad y_{TAI} - y_{Cs}(NIST) \text{ on geoid} = (+0.3 \pm 0.7) \times 10^{-13} \text{ (July 1987)}$$

This algorithm should provide nearly optimum accuracy and stability for TA(NIST) since it uses all past frequency calibrations with the NIST primary standards. These calibrations are weighted proportionately to the frequency memory of the clock ensemble that generates atomic time. This algorithm, therefore, capitalizes on a weighted combination of all the frequency calibrations with the primary standards in order to gain a "best estimate" of the SI Second while simultaneously obtaining the best uniformity available from the ensemble of working clocks in the atomic time scale system. The relative frequency of TA(NIST) is steered toward $y_{Cs}(NIST)$ by slight frequency drift corrections of the order of 1 part in $10^{13}/\text{yr}$.

TA(NIST) and UTC(NIST) are no longer simply related by an equation. TA(NIST) is now computed each month using a Kalman algorithm which minimizes the mean square time dispersion. UTC(NIST) is now independently computed using a different algorithm and is steered in frequency to keep its time within a microsecond of UTC(BIH). Table 7.1 lists monthly values of the time difference between UTC(NIST) and TA(NIST). A linear interpolation between monthly values will typically be within 10 ns of the actual time difference, TA(NIST) - UTC(NIST).

The primary standards of NIST (NBS-4 and NBS-6) are used in either of two modes: as calibrators of frequency to provide a reference for the SI second; or as member clocks of the NIST clock ensemble, to help keep the proper time for TA(NIST) and the coordinated time for UTC(NIST). Operating in the clock mode, NBS-4 and NBS-6 are only used and weighted according to their stability performance. Accuracy enters only when they are used as frequency calibrators, in which case clock operation is necessarily interrupted.

¹GPS is the Global Positioning System, a network of navigation satellites.

Table 7.1 is a list of changes in the time scale frequencies of both TA(NIST) and UTC(NIST) as well as a list of the time and frequency differences between TA(NIST) and UTC(NIST) at the dates of leap seconds, and/or frequency or frequency drift changes.

TABLE 7.1

FREQUENCY CHANGES					
DATE	(MJD)	TA(NIST)	UTC(NIST)	TA(NIST) - UTC(NIST)	$y[\text{UTC(NIST)}] - y[\text{TA(NIST)}]$
1 Nov 88	47466	0	1.25 ns/d	24.045 116 854 s	-4.88 E-13
1 Dec 88	47496	0	1.50 ns/d	24.045 118 088 s	-4.69 E-13
1 Jan 89	47527	0	1.50 ns/d	24.045 119 325 s	-4.57 E-13
1 Feb 89	47558	0	1.00 ns/d	24.045 120 538 s	-4.51 E-13
1 Mar 89	47586	0	-1.25 ns/d	24.045 121 622 s	-4.58 E-13
1 Apr 89	47617	0	-1.50 ns/d	24.045 122 871 s	-4.66 E-13
1 May 89	47647	0	-1.50 ns/d	24.045 124 078 s	-4.75 E-13
1 Jun 89	47678	0	-1.00 ns/d	24.045 125 375 s	-4.92 E-13
1 Jul 89	47708	0	-1.00 ns/d	24.045 126 670 s	-5.09 E-13
1 Aug 89	47739	0	-1.00 ns/d	24.045 128 060 s	-5.35 E-13
1 Sep 89	47770	0	-1.00 ns/d	24.045 129 538 s	-5.58 E-13
1 Oct 89	47800	0	1.00 ns/d	24.045 131 001 s	-5.68 E-13
1 Nov 89	47831	0	1.00 ns/d	24.045 132 534 s	-5.85 E-13
1 Dec 89	47861	0	1.00 ns/d	24.045 134 082 s	-6.05 E-13
1 Jan 90	47892	0	1.00 ns/d	24.045 135 724 s	-6.16 E-13
1 Feb 90	47923	0	1.00 ns/d	24.045 137 382 s	-6.21 E-13
1 Mar 90	47951	0	1.00 ns/d	24.045 138 888 s	-6.23 E-13
1 Apr 90	47982	0	1.00 ns/d	24.045 140 560 s	-6.36 E-13

UTC(NIST) is steered in time toward UTC by occasional frequency changes of the order of a few nanoseconds per day; 1 ns/d is approximately $1.16\text{E-}14$. Otherwise, $y[\text{UTC(NIST)}]$ is maintained as stable as possible.

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Allan, D.W. and Weiss, M.A., "Accurate Time and Frequency Transfer During Common View of a GPS Satellite," *Proc. 34th Annual Symposium on Frequency Control*, p.334 (1980).

Allan, D.W. and Barnes, J.A., "Optimal Time & Frequency using GPS signals," *Proc. 36th Annual Symposium on Frequency Control*, p.378 (1982).

8. SPECIAL ANNOUNCEMENTS

44TH ANNUAL FREQUENCY CONTROL SYMPOSIUM

The 44th Annual Frequency Control Symposium will be held May 23 - 25, 1990 in Baltimore, MD. This symposium is the leading technical conference addressing all aspects of frequency control and precision timekeeping. Authors are invited to submit papers dealing with recent progress in research, development and applications in areas represented by the following topics:

- Fundamental properties of piezoelectric crystals
- Theory and design of piezoelectric resonators
- Resonator processing techniques
- Filters
- Surface acoustic wave devices (SAW)
- Quartz crystal oscillators
- Microwave and millimeter wave oscillators
- Signal processing and frequency control circuitry
- Atomic and molecular frequency standards
- Frequency and time coordination and distribution
- Sensors and transducers
- Applications of frequency control
- Measurement and specifications

Contact: Dr. R. L. Filler, US Army Electronics Technology and Devices Laboratory, ATTN: SLCET-EQ, Fort Monmouth, NJ 07703-5000; (201) 544-2467.

NOBEL PRIZE WINNERS to SPEAK at the 44th ANNUAL

SYMPOSIUM on FREQUENCY CONTROL

The 1989 Nobel Prize in Physics was awarded to Norman Ramsey, Hans Dehmelt, and Wolfgang Paul for advancements in atomic clock technology. Professor Ramsey of Harvard University and Professor Dehmelt of the University of Washington (and possibly Professor Paul from the University of Bonn) have accepted invitations to present their Nobel lectures at the 44th Annual Symposium on Frequency Control. There will be a special reduced registration fee for the Nobel lectures. The lectures will be presented Friday morning, May 25.

Professor Ramsey's talk is titled "Experiments with Separated Oscillatory Fields and Atomic Hydrogen Masers." Professor Dehmelt's talk is titled "Experiments with an Isolated Subatomic Particle at Rest."

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